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Cost Reduction of Electric Oven Machine Using Design for Manufacture and Assembly (DFMA)

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Abstract: Every industry needs to manufacture low cost, high quality and quicker time on the market. Design for Manufacturing and Assembly (DFMA) is a methodology used to reduce or redesign many products in the manufacturing sector. The benefit of DFMA is that it can reduce the manufacturing cost. The primary purpose of this study is to propose a new design for the electric oven. Besides that, the manufacturing cost, assembly time and design efficiency are analyzing to support the modifications. The analyses will be carried out by disassembling the electric oven, each component's operation, and 3D modelling using SolidWorks software. Lastly, DFMA design guidelines are used to create a new design. The selection criteria for a successful design are based on the cost of manufacture and assembly time. Finally, the method chosen has been proven to meet the relevant requirements by improving the operation cost, operation time and design efficiency. The existing product design efficiency is 32.00 %, and the new design is 44.00 %. The operation time for a new design is also improving from 123.53 s per unit to 89.08 s per unit. In this study, the overall operation cost reduction is RM13.77, and the percentage reduction is 27.88 %.

Keywords: Design for Manufacturing and Assembly, DFA, Electric Oven, Reduce Cost

1. Introduction

The DFMA approach aims to close the distance between design and manufacturing workforce. Developers should be aware of the efficiency capabilities of their own company for manufacturing and assembly. It would make it possible to reduce or remove the future challenges in the production and assembly processes [1]. Therefore, when designing a new product, DFMA will be used at the early stage of the project design to define the product's requirements. The DFMA approach offers many other advantages for the product, such as product quality, reduction of the number of components, ease of assembly procedures, standardization, flexibility and cost reduction [2].

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The DFMA method tests the product based on design performance. Higher design efficiency best product. The number of sections of the product has a significant impact on the importance of design performance. If the product has a lot of components, the assembly time would be higher. Higher assembly time means lower performance design. Higher manufacturing time explicitly implies that the production costs are higher. DFMA is a tool for evaluating the manufacturing capability of the design and assembly of components. This is a way to classify unused sections of the assembly and determine the time of development and assembly costs[3].

1.1 Design for Assembly (DFA)

The design phases in the early stages of the DFA method should be carefully analysed so that costs and time can be correctly estimated. The design of the team should deliver sustained results and make it easy to use. It should also ensure accuracy and completeness in the production of its product assembly. Aside from this, for the manufacturer and the designer engineer, interaction is very critical and needs to be improved. The concept, reasoning, and decision made during the design process are well recorded for future references[4].

DFA is a product design that makes it simple to assemble. It uses a systematic approach to predict production times and costs step by step at an early stage. In the designer and the supplier, it is vital to understand the structure of the product. The purpose is to adjust the design of components, and the effects of such a change must be documented immediately[4].

1.2 DFA Guidelines

The DFA guideline has been defined in several ways as it comes from various authors. Some author explains it in-depth, while some of them only classified it in a few lists, divided in concept to another theory. Nevertheless, the key goal of DFA is to reduce the expense of assembly [5]. Guideline as follows:

i. Reduce the number of parts:
   This can be achieved by reducing the total number of fasteners and designing the product with fewer parts.
ii. The minimum size of components:
   Lower number of parts, lower assembly costs. It can be achieved by eliminating non-essential parts, but the system is still working and eventually integrating a multiple-element into a single part.
iii. Minimizing the number of fasteners and their components:
   Screw and washer will increase assembly costs and time. To minimize costs, screws, nuts, and washers may be replaced by alternative fasteners such as the snap-fit design on the product, molded hinges brace or hook, and press fit.

1.3 Electric Oven

The oven is a small electrical kitchen device built to heat or bakes various types of items. The design has undergone several changes, from purely mechanical to automatic, with some complexity [6]. The first ovens were found in Central Europe, dated 29,000 B.C., and were used as roasting and boiling pits located within yurt structures. Since the prehistoric period, the ovens have been used by cultures living in the Indus Valley and pre-dynastic Egypt [7].

The electric oven works on the theory of electrical resistance. Due to the resistance to the current flow, the heating element has been heated up and the voltage indicator shows a green light confirming the presence of the current. When the light is turned on, the red indicator means that the oven is in operation. The basic operating principle of the electric oven is the method of heat transfer. Heat transfer by conduction, convection, and radiation continues to occur if there is a difference in temperature [8].

Figure 1 below show the electric oven chosen for this study. The oven can simply be described as a completely enclosed, insulated chamber used to heat food. There are several variants of this basic principle in the commercial kitchen, but each type of commercial oven cooks by regulating the temperature and humidity of the oven. The flexibility of the oven makes it useful in many forms of food service operations [9]. The oven is constructed in such a way that the electrical source (heating element) and the gas source (gas burner) are combined into one chamber to reduce the waste of material that would have been used to create two separate chambers for both sources [10].

Figure 1: Electric oven

2. Materials and Methods

As DFMA methodology, the DFA Manual Analysis approach was chosen to study the selected product. Therefore, the method of manual DFA analysis determined by Boothroyd and Dewhurst is practical to be tested.

2.1 Methods

The manual review of the DFA is normally carried out in five stages of:

i. Disassembled component and description of parts.

ii. Evaluation of the assembly process (Boothroyd Dewhurst Method)

iii. Definition and improvement of the parts proposed.

iv. Re-evaluation of modified parts (Boothroyd Dewhurst Method)

v. Evaluation of original and improved parts.

2.2 Product part details

The electric oven is chosen as the product chosen for this research. The complexity of the design and the number of components has an impact on the prices of the product. The first step is to disassemble the oven into parts. Upon disassembly, the component consists of 16 or more main parts as the number of fasteners of the components does not count. Table 1 shows the electric oven parts name and the quantity of the parts.

Table 1: Part details

Part No.	Part Name	Quantity
1	Outside casing	1
2	Back cover	1
3	Front casing	1
4	Glass holder	1
5	Scanner glass	1
6	Knob	3
7	Power cord cover	4
8	Power cord	4
9	Upper housing	1
10	Bottom inside casing	1
11	Bottom cover	1
12	Heat rack	2
13	Metal rack	1
14	Bake pan	1
15	Oven door	1
16	Spring	1
17	Door handle	1
18	Feet	4

2.3 Assembly process evaluation (Boothroyd Dewhurst)

The evaluation of the assembly using the Boothroyd method will be carried out in this study where, first, the use of the DFA worksheet table as shown in Figure 2. The evaluation procedure for the DFA Worksheet can be described as:

i. Description of the parts and the quantity:

As described in Figure 2, the dimensions and number of the components are measured in this DFA worksheet

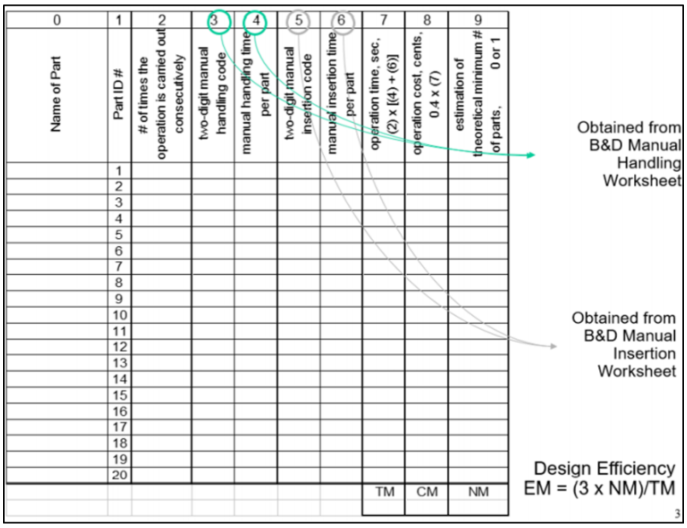
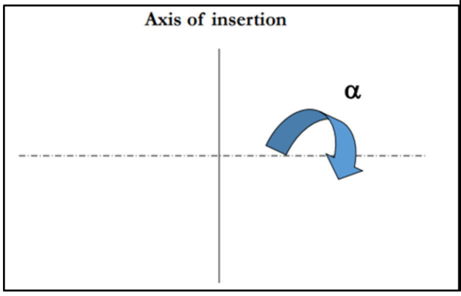


Figure 2: Manual DFA worksheet [11]

ii. The determine of the effect of part symmetry of each part:

As an essential factor for the assembly process, part of symmetry on handling is vital. There are two kinds of equality that are alpha symmetry and beta symmetry. Figure 3 shows the rotation of the alpha symmetry, where rotated about an axis perpendicular to the rotation axis. Meanwhile, beta symmetry rotation is on the axis of insertion, as shown in Figure 4.



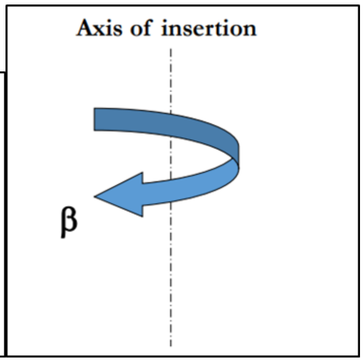


Figure 3: Alpha symmetry rotation [11] **Figure 4: Beta symmetry rotation [11]**

iii. Manual Worksheet Evaluation Handling:

Using the handling symmetries, α and β, and the information of the parts in, the two-digit handling code and the time taken for manual handling of each piece are obtained by manual handling, as shown in Figure 5.

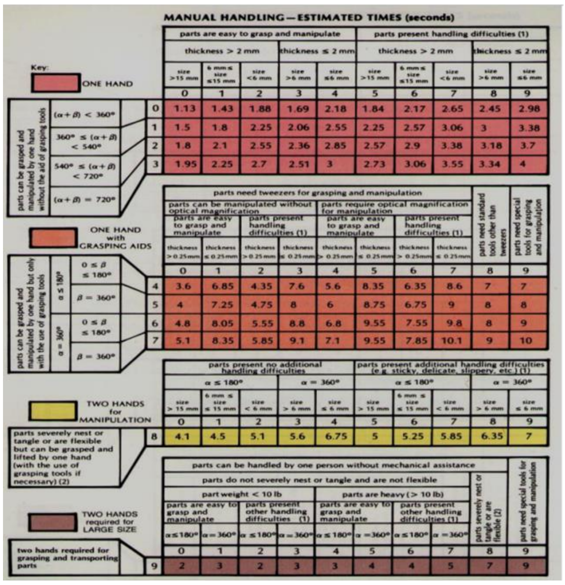


Figure 5: Manual handling worksheet [11]

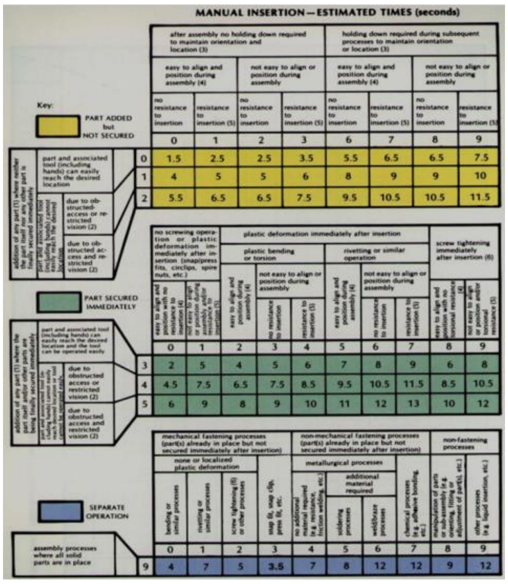


Figure 6: Manual insertion worksheet[11]

iv. Evaluation of the manual insertion worksheet:

Manual insertion worksheet assessment showed when Figure 6 also uses the handling symmetries, α and β, and the parts described to achieve two-digit manual insertion and time taken for each part during insertion.

v. Time of operation and cost calculation:

The operation time can be determined by the quantity of the part multiplied by the amount of manual handling and the time of insertion taken for each part. For the cost of operation, a scale of 0.4 is used to quantify the efficiency of the design. The cost of operation can be measured as 0.4 multiplied by the times of operation before each component.

vi. Estimation of theoretical minimum parts:

For the value of the calculation for potential minimum pieces. There are rules to be followed at this point, such as:

• Does the part move relative to all other assembled parts during the operation of the product?

• Does the element component have to be different from the pieces already assembled?

• The part must be separated from all the parts already assembled?

3. Results and Discussion

This section focuses mainly on the results of the review of the data. This section aims to improve the study's goal by reducing the number of parts and making a better quality product than the original design. These analyses will be carried out via the DFA Manual.

3.1 Manual DFA analysis on original design

Table 2 below shows the analysis of the original design of an electric oven. The study has been done using DFA table. The table will generate the operation time, operation cost and design efficiency on the original design.

Table 2: DFA table analysis on original design of electric oven

DESIGN FOR MANUAL ASSEMBLY - WORKSHEET									
1	2	3	4	5	6	7	8	9	
Part No	Operations	Handling Code	Handling Time	Insertion Code	Insertion Time	Operation Time	Operation Cost	Minimum No Parts	Name of Assembly
18	4	00	1.13	30	2	12.52	5	0	Feet
17	1	40	3.6	30	2	5.6	2.24	1	Door handle
16	1	42	4.35	40	4.5	8.85	3.54	1	Spring
15	1	40	3.6	30	2	5.6	2.24	1	Oven door
14	1	00	1.13	00	1.5	2.63	1.05	1	Bake pan
13	1	00	1.13	00	1.5	2.63	1.05	1	Metal rack
12	2	88	6.35	11	5	22.7	9.08	1	Heat rack
11	1	80	4.1	38	6	10.1	4.04	0	Bottom cover
10	1	88	6.35	40	4.5	10.85	4.34	1	Bottom inside casing
9	1	88	6.35	30	2	8.35	3.34	1	Upper housing
8	4	40	2.18	00	1.5	7.36	2.94	1	Power cord
7	4	23	2.7	00	1.5	4.2	1.68	1	Power cord cover
6	1	10	1.5	30	2	3.5	1.4	0	Knob
5	1	23	2.36	00	1.5	3.86	1.54	1	Scanner glass
4	1	10	1.5	00	1.5	3	1.2	1	Glass holder
3	1	30	1.95	00	1.5	3.45	1.38	1	Front casing
2	1	41	2.55	00	1.5	3.83	1.53	0	Back cover
1	1	43	3.0	00	1.5	4.50	1.8	0	Outside casing
		Total				123.53	49.39	13	Design Efficiency = 3 NM/TM = 0.32 @ 32%
						TM	CM	NM	

3.2 Assembly Cost and Design Efficiency of Original Design

From Table 2, the original electric oven consists of 18 main parts as the number of fasteners of the components does not count. The analysis started by listing all the components and parts and arranges it correctly in sequences order. After that, the sequences data acts as input to be inserting on the DFA table thus the result can be generated. The operation time per unit is 123.53 second and the operation cost per unit is RM 49.39. The design efficiency can be calculated by using equation 1 below

$$Design\ efficiency = (3s\ NM\ /\ TM)\ x\ 100\% \qquad Eq. 1$$

$$= ((3 \text{ x } 13) / 123.53) \text{ x } 100\%$$

= 32%

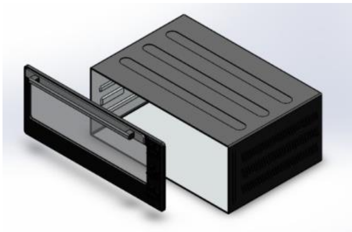
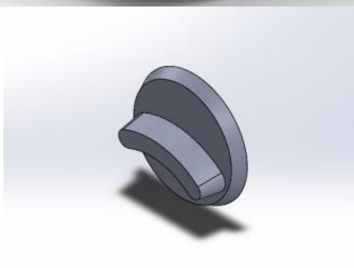
TM = total operation time

NM = theoretical minimum number of part

3.3 Design Modification of Electric Oven

Modifications are usually performed on the original parts without modifying their features. It is done to reduce the number of components, time and expense of the assembly process. The efficiency of the design can be improved by removing the unnecessary part. The assembly process is more straightforward, as it is considered a modern design approach by designing the modification. A few changes to the design were obtained from the analysis, which can be applied if manufacturing costs are reducing significantly. Table 3 below shows the modification suggestion for electric oven.

Table 3: The modification suggestion for electric oven

Part	New design
Outside casing and back cover (combining two part to become one part)	
Heat rack (consist two parts convert to one part)	
Knob (change the material from plastic to aluminum)	
Feet (all four feet combine with the bottom cover)	

3.4 Manual DFA analysis on redesign electric oven

Table 4 below shows the analysis of the redesign of an electric oven. The study has been done using DFA table. The table will generate the operation time, operation cost and design efficiency on the redesign electric oven.

Table 4: DFA table analysis on redesign electric oven

DESIGN FOR MANUAL ASSEMBLY - WORKSHEET									
1	2	3	4	5	6	7	8	9	
Part No	Operations	Handling Code	Handling Time	Insertion Code	Insertion Time	Operation Time	Operation Cost	Minimum No Parts	Name of Assembly
13	1	40	3.6	30	2	5.6	2.24	1	Door handle
12	1	42	4.35	40	4.5	8.85	3.54	1	Spring
11	1	40	3.6	30	2	5.6	2.24	1	Oven door
10	1	00	1.13	00	1.5	2.63	1.05	1	Bake pan
9	1	00	1.13	00	1.5	2.63	1.05	1	Metal rack
8	2	88	6.35	11	5	22.7	9.08	1	Heat rack
7	1	88	6.35	40	4.5	10.85	4.34	1	Bottom inside casing
6	1	88	6.35	30	2	8.35	3.34	1	Upper housing
5	4	40	2.18	00	1.5	7.36	2.94	1	Power cord
4	4	23	2.7	00	1.5	4.2	1.68	1	Power cord cover
3	1	23	2.36	00	1.5	3.86	1.54	1	Scanner glass
2	1	10	1.5	00	1.5	3	1.2	1	Glass holder
1	1	30	1.95	00	1.5	3.45	1.38	1	Front casing
		Total				89.08	35.62	13	Design Efficiency = 3 NM/TM = 0.44 @ 44%
						TM	CM	NM	

3.5 Assembly Cost and Design Efficiency of Modified Electric Oven

From Table 2, the redesign electric oven consists of 13 main parts as the number of fasteners of the components does not count. The analysis started by listing all the components and parts and arranges it correctly in sequences order. After that, the sequences data acts as input to be inserting on the DFA table thus the result can be generated. The operation time per unit is 89.08 second and the operation cost per unit is RM 35.62. The design efficiency can be calculated by using equation 1 below.

$$Design\ efficiency\ =\ (3s\ NM\ /\ TM)\ x\ 100\% \qquad Eq. 2$$

$$= ((3 \text{ x } 13) / 89.08) \text{ x } 100\%$$

$$= 44\%$$

TM = total operation time

NM = theoretical minimum number of part

3.6 Discussion

Original and redesign parts have been analyzed using DFA manual worksheet. The modification had been done on six parts, which consist of reducing the use of screws and combining two elements to become one part. The outside casing and back cover are coupled to be one part. Combining the piece did not affect its feature, but provides more advantages by reducing the number of components and the time of assembly. The outside casing and back cover operation is a snap-fit consisting of a total of five snap fits.

By combining the component, the snap-fit procedure is reduced to two, thus reducing the time for assembly. The heat rack consists of two parts, also connected to be one part. At the same time, the original knob material is plastic and is converted to aluminum. By changing the content will reduce the manufacturing cost, thus will affect the overall cost. All four parts of the feet are combined with the bottom cover, and it will make it easier for manufacturers to design their products. The DFA index for the redesign is increased due to the change that has been made. This indicates that the assembly complications during the production process have also been minimized.

Figure 7 below shows the relation between the original design and the improved design would be distinguished according to the discussion for this project. Firstly the original concept can be reduced to 10 different sections from 16 different parts. As previously mentioned guidelines for the DFMA technique, assembly can be quick when the number of parts is reduced and this modified design can assist the assembly process. In addition, manual analysis of Boothroyd Dewhurst DFA will be used to evaluate both the original design and the improved design to obtain design efficiency. The original design of the oven with operation time per unit is 123.53 s and the operation cost per unit is RM49.39 had the design efficiency of 32.00 %. Whereas, the modified design oven with 44.00 % efficiency will reduce the cost and time of operation with RM35.62 and 89.08 s respectively.

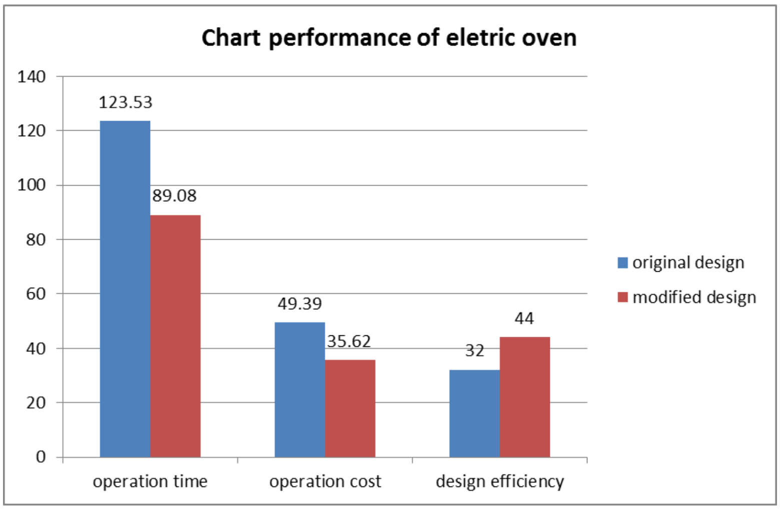


Figure 7: Comparison between original and redesign electric oven

4. Conclusion

The research's primary purpose is to evaluate the current product and develop the design of the electric oven using the Design for Manufacturing Assembly process. The factors needed in this research include improving the quality of the product chosen, reducing the number of components and parts, and reducing the cost of the product. The DFA table is used in this research by contrasting the original and redesigned findings. The overall assembly time is reduced by 89.08 s per product. While the total cost based on the DFA table's output indicated an original is RM49.39, and redesign is RM35.62. Finally, the comparison between the original and the redesigned product's design efficiency is 32.00 % and 44.00 %. All of this demonstrates that this study has met all of the objectives.

4.1 Recommendation

For the recommendation, there are some improvements can be done in order to optimize the design of oven. Even though the DFMA is the improve method that cutting down the cost of manufacturing assembly in the industry and the purpose of the analysis is to compare products with relative design performance. Therefore there are still spaces to improve.

First, the aspect that can be improved is speed. One of the aspects of DFMA in construction is the significantly reduced programmed on-site through the use of prefabricated elements. For the improved design, the speed of designing can be done much faster if eliminate or change any unnecessary according to customer needs. Next, assembly cost can be reducing to the minimum value. The DFMA is a method that using fewer parts. By doing that, it decreasing the amount of labor required, and reducing the number of unique parts, DFMA can significantly lower the cost of assembly. To make sure the DFMA is running with efficiently, the knowledgeable labor are crucial need.

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